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1.2) The loess deposits of the Rivoli moraine system.

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Abstract. In the Rivoli and Val Sorda areas thick loess sequences are preserved. Radiocarbon, OSL datings and archaeological evidence refer the loess sedimentation back to the first Pleniglacial period of the Upper Pleistocene. Loess deposits are generally covered by till or fluvioglacial gravel and include chernozem type soils. Where they outcrop at the surface, they have been affected by decalcification and clay illuviation as a consequence of the Holocene soil-forming processes. Pollen analyses carried out in the Val Sorda loess indicate that loess sedimentation occured in a dry environment ranging from cold steppe, lacking arboreal plants, to wooded grassland with few thermophilous plants.

Riassunto. Nell'area di Rivoli e della Val Sorda si trovano spesse successioni di depositi loessici, che, grazie al materiale archeologico contenuto, a datazioni radiocarboniche e di OSL, sono attribuite al primo periodo Pleniglaciale dell'ultima glaciazione. In genere i loess sono sepolti da depositi morenici e fluvioglaciali e sono intercalati da suoli di tipo chernozemico; quando invece affiorano alla superficie, risultano interessati dalla pedogenesi olocenica che ne ha provocato la decarbonatazione e l'accumulo dell'argilla illuviale. Lo studio palinologico della successione stratigrafica della Val Sorda indica che la deposizione del loess è avvenuta in ambienti aridi, oscillanti tra la steppa fredda e la prateria arborata.

1.2.1) Introduction.
(M. Cremaschi)

The area is situated where the Adige River flows out of its pre-Alpine valley and into the plain of the Po river, in a key position of the Alpine system. Indeed, several faults of Judicariensis trend (NNE-SSW) put the Lessini plateau, developed during the late Cenozoic period, into contact with an area (Mt. Baldo, Brescia) of different tectonic style, in which complex tectonic compressive structures -namely reverse faults-occur.

These lineations had already developed during the Secondary Era, but moved also in Tertiary and Quaternary periods, and strongly affected the geo-morphological evolution of the landscape (fig. 1).

The Adige valley, particularly deep and narrow in its pre-Alpine tract, turns out to be parallel to said contact. A certain amount of geological evidence of Pleistocene climatic fluctuations is preserved in this area, indicating that the Alpine glaciers reached the piedmont area several times. Moraine ridges of the Garda system face a smaller but well preserved system of frontal moraine ridges, close to the Rivoli village, deposited by the glaciers descending along the Adige Valley; thick loess covers, Terra Rossa-type soils, and fluvioglacial terraces are also preserved.

This evidence has long attracted the interest of european Quaternary geologists who first studied the evidence of the Glacial period at the southern border of the Alps (NICOLIS, 1899; PENCK & BRUCKNER, 1909; COZZAGLIO, 1931). More recently, the area has been accurately mapped by VENZO (1957), and studied from a stratigraphical and palaeopedological point of view by MANCINI (1960), FRAENZLE (1965) and HABBE (1969). Great attention has been paid to the stratigraphic sequence of the Val Sorda cut, in which, below an Upper Pleistocene moraine, loess and paleosols outcrop (NICOLIS, 1899; COZZAGLIO, 1931; MANCINI 1960; FRAENZLE, 1965; HABBE, 1969; CREMASCHI, 1987a; CREMASCHI et al. 1987).

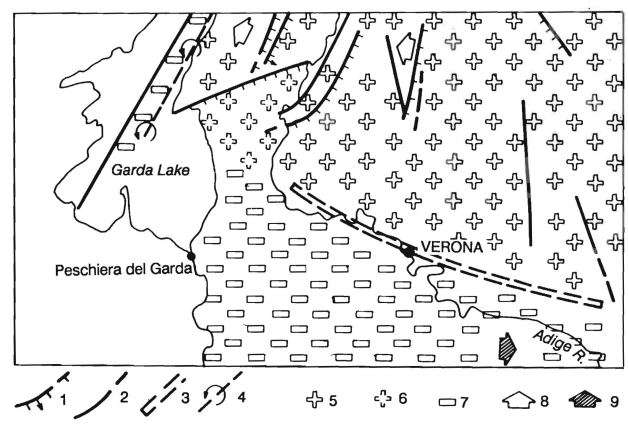

Fig. 1. Neotectonic map of the area East of the Garda lake (from C.N.R., neotectonic map of Italy, in print); 1, 2 - faults; 3 - deformation belt; 4 - tilting axis; 5, 6 - uplifting areas; 7 - subsiding areas; 8 - differentiate uplifting; 9 - differentiate subsiding.

Fig. 1. Carta neotettonica dell'area ad est del Lago di Garda (tratta da: C.N.R. Carta Neotettonica d'Italia, in stampa).; 1, 2 - faglie; 3 - fascia di deformazione; 4 - asse di basculamento; 5, 6 - aree in sollevamento; 7 - aree in abbassamento; 8 - innalzamento differenziato; 9 - abbassamento differenziato.

Given the wealth of stratigraphic evidence,

Fig. 2. The Geological map of the Quaternary deposits of the Rivoli area.

Fig. 2. Carta geologica dei depositi quaternari dell'area di Rivoli.

- **Tasso unit:** alluvial deposits of the Tasso creek *(Holocene)*
- **Gaium unit:** alluvial terraces of the Adige River *(Holocene)*
- **Ceraino unit:** alluvial terraces of the Ceraino village *(Late Glacial)*
- **Rivoli unit:** glaciolacustrine deposits of the Rivoli village and deposits of the Late Glacial paleochannel of the Adige River *(Late Glacial)*
- **Zuane unit:** Kame terraces and fluvioglacial deposits related to the retreat of the Garda and Rivoli glaciers *(Upper Pleistocene)*
- **Fiffaro unit:** moraine ridges related to the retreat of the Garda and Rivoli glaciers *(Upper Pleistocene)*
- **Albare unit:** fluvioglacial deposits related to the above moraine ridges *(Upper Pleistocene)*
- **M.te Police unit:** moraine ridges of the greatest glacial expansion *(Upper Pleistocene)*
- **Cocche unit:** fluvioglacial deposits related to the above moraine ridges *(Upper Pleistocene)*
- **Affi unit:** slope deposits *(Upper Pleistocene)*
- **M.te Moscal unit:** widest loess outcrops *(Upper Pleistocene)*
- **M.te Crivellino unit:** eroded moraine ridges *(Middle Pleistocene)*
- **Albare unit:** very eroded moraine ridges cemented fluvial gravel *(Middle Pleistocene)*
- **Caprino unit**: very eroded moraine ridges *(Early Middle Pleistocene)*
- **Pesina unit:** dissected moraine deposits *(Early Pleistocene)*
- **Forte unit:** strongly cemented gravel *(Early Pleistocene)*
- Pre-Quaternary bedrock mainly limestones
- main scarps in limestone
- main scarps
- alluvial fan
- paleochannel of the Adige river
- possible buried canyon of the Adige river
- moraine ridge

Fig. 2a. The legend of the geological map.

Fig. 2a. Legenda della carta geomorfologica.

the Val Sorda sequence constitutes a stratigraphic reference point for the detailed study of the area's palaeoenvironmental variations throughout the entire Upper Pleistocene. More recently, attention has been paid to the area surrounding the moraines and the related fluvioglacial system, which consists of dissected paleosurfaces bearing Terra Rossa-type soils, covered by polygenetic loess covers (MAGALDI & SAURO, 1982).

1.2.2) The Rivoli moraine system.
(M. Cremaschi)

We are dealing here with a moraine system of regular semicircular form, made up of several concentric arcs which grade down towards the course of the Adige river. Because of the perfect conservation of the moraines and for reasons of stratigraphic nature which will be discussed later on, this structure is to be dated Upper Pleistocene. In establishing a relation between the form and extension of the frontal moraines and the outcrops of bedrock, it becomes obvious that the distribution of these moraines is the result of the westwards encroachment, caused by a substantial rocky obstacle along the axis of the valley itself, of the Adige glacier (fig. 2,3).

Geomorphological analysis allows us to recognize a complex genesis in the system's make-up: a prominent and continuous ridge of fresh morphology (Mt. Ceredello - Montalto - Mt. Police and Mt. La Mesa) constitutes the local watershed. This represents the frontal moraine of the Adige glacier's greatest expansion (M.te Police unit; see map). Its ridge top, not homogeneous, occasionally shows redoubling, as at Mt. Zovo. At its southern edge, near the village of Lubiara, we can observe another lobed moraine ridge, the limbs of which rise oblique to the slope of Mt. Cordespino. These deposits testify to the fact that along this tract the glacier overspilled the western margin of the valley.

Within the main moraine ridge are three orders of concentric moraines progressively grading down towards the center of the moraine system near the Castle of Rivoli. We are dealing here with discontinuous moraine circles which mark the boundaries of stretches of fluvioglacial plain and alternate with kame terraces where the moraine ridges have not been preserved (Rivoli, Zuane and Fiffaro units). The stratigraphy of the Kame terrace has been exposed in quarries excavated in the terrace itself. An example (cave La Rossa) it consists of two main units: the underlying unit consists of gravelly foresets of a fan delta which had originated in the N-E.

These foresets grade into glaciolacustrine deposits which consist of planar-bedded silts alternating with cross-bedded sands. The overlying unit is made up of coarse planar-bedded, discontinuous gravels and sands of fluvioglacial facies, and is covered by a soil with a slightly rubified Bt horizon.

In the southern tract of the Rivoli moraine system, at Mt. Police, the various moraine orders elsewhere spaced out, separated by fluvioglacial terraces, are here amassed - one up against the other - as a result of a limestone ridge which is still cropping out of the moraines and which has hindered the expansion of the glacier.

The moraines of the Monte Police unit cover, in its Eastern part, slope deposits, loess, and

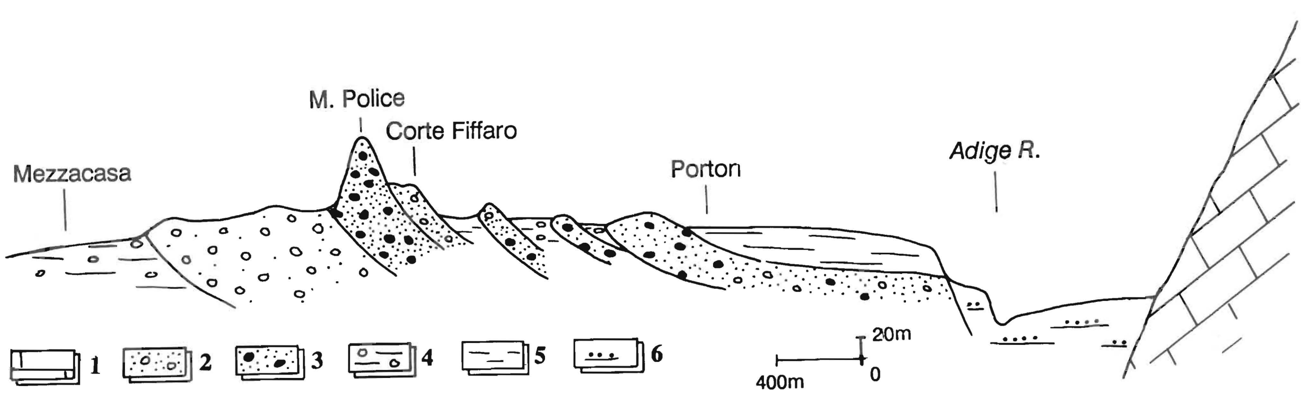

Fig. 3. Geological cross section of the moraines ridges of the Rivoli area; 1 - limestone bedrock; 2 - eroded moraines (late Middle Pleistocene); 3 - well preserved moraines (Upper Pleistocene); 4 - outwash fan and Kame deposits (Upper Pleistocene); 5 - lacustrine deposits (Late-Glacial); 6 alluvial deposits into the Adige valley (Holocene).

Fig. 3. Sezione geologica dell'anfiteatro morenico dell'area di Rivoli; 1 - substrato calcareo; 2 - morene rimodellate dall'erosione (tardo Pleistocene medio); 3 - morene ben conservate (Pleistocene superiore); 4 - depositi fluvioglaciali e di sbarramento glaciale (Pleistocene superiore); 5 - depositi lacustri (Tardiglaciale); 6 - depositi fluviali all'interno della valle dell'Adige (Olocene).

rubified paleosols (see par. 1.2.4) contained in a depression carved into the bed rock. Due to the occurence of quartz and metamorphic pebbles into the paleosol, the depression could represent a paleochannel of the Adige river, at least older than the last Glacial period.

A wide, flat-bottom valley branches off towards the South from the glaciolacustrine deposits (Rivoli unit) located in the most central nucleus of the moraine orders. This valley represents the course carved out by the Adige during Deglaciation, before the present canyon (Chiuse d'Adige), down which the river now flows, was opened. New elements which serve the purpose of dating the event have been provided by the stratigraphic sequence which came to light in the Soman rock shelter (BROGLIO & LANZINGER, 1984) located near the village of Ceraino, three kilometers North of the Adige canyon and about ten meters above its current river-bed. This sequence consists of, from bottom to top (fig. 4):

- gravelly bar and overbank deposits of the Adige river;
- thermoclastic breccia, sometimes cemented, including fauna and Epigravettian implements at the top;
- fine deposits, mainly colluvial and anthropogenic, including Mesolithic and Neolithic implements.

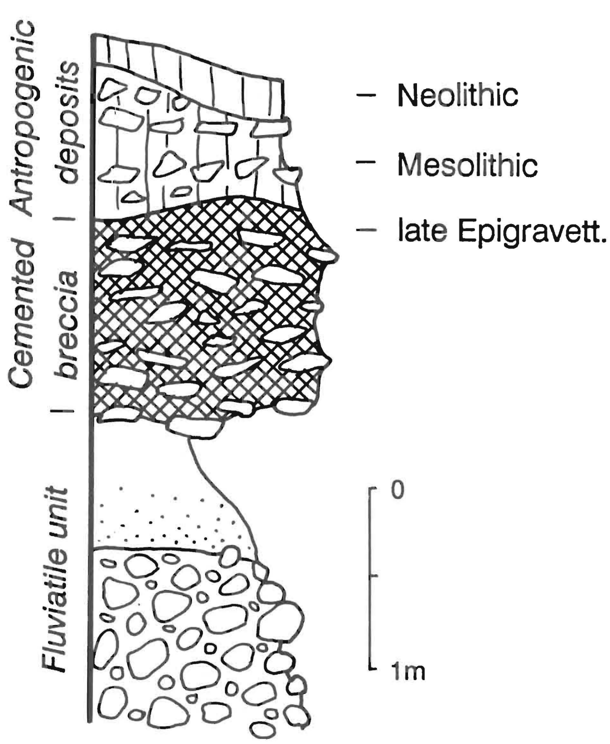

Fig. 4. The stratigraphic sequence of the Soman shelter.
Fig. 4. La successione stratigrafica del Riparo di Soman.

Thanks to the Late Palaeolithic artifacts contained in it, the thermoclastic breccia can be referred to the cold recent Dryas period. Thus, in the 11th millenium B.C., the Adige flowed at a slightly higher level than today's, into the plain of the Po through the canyon.

The outwash plain that opens out from the eskers carved in the main moraine ridges encompasses the remains of an older moraine system (Mt. Crivellino unit) which differs from this system in that it consists of flattened moraines. These moraines are severely eroded and, for the moment, are attributed to the penultimate glacial period. Their planimetric distribution reveals a more marked lobing towards the South-West. Moraines are missing from this phase in the area adjacent to the Adige river, where they have probably been buried by those of the Upper Pleistocene. Traces of till deposits, which can be dated early Middle Pleistocene and perhaps Early Pleistocene, can be found near Montecchio and Caprino (Pesina and Caprino units), leaning up against the margin of Mt. Belpo; but no element is as yet available with which we can date these deposits.

The soils which developed upon the Rivoli moraine system and the fluvial and fluvioglàcial deposits linked to it consist of fersiallitic brown soils, calcic brown soils, rendzinas and lithosols, all products of late - and post-glacial soil forming processes. No evidence of paleosols can be found in the area, possibly as a result of the intense erosion which affected the pre-existing landscape during the last glacial period. Brunified soils, sometimes eroded, can be found on the top of the fluvioglacial terraces. The distribution of soil types is more complex upon the ridges of the moraines. Catenary sequences of soils consist here of lithosols at the very top of the moraines, of rendzinas and calcic soils along the slopes. Complex profiles, including colluvial cover and fersiallitic brown soil with Bt horizon (Haploxeralfs), are preserved at the most depressed part of the moraine ridges. A characteristic example of such profiles is provided by the one observed at Case Zuane:

A1+B1 cm 0-31: sandy loam, strong brown (10 YR 4/4); few to common limestone and volcanic stones, fine subangular blocky, poorly developed; common to many voids; clear boundary to:

II B2t cm 31-126: sandy clay loam, reddish brown (5 YR 5/4); few fragments of volcanic and metamorphic rock; medium blocky; small common clay cutans into pores and on peds; clear undulated boundary to:

II Cca cm 126-150: sandy loam and many unweathered stones (limestone, dolomia, chert, metamorphic and volcanic rock); loosely cemented by $CaCO_3$; not exposed boundary.

This complex profile reflects the different phases of Holocene pedogenesis. The evolution of the fersiallitic brown soil II B2t provides evidence for the oldest phase. In all probability, this soil originally extended along a greater part of the ridges of the moraines from which it was later eroded. The ensuing colluvial deposits then descended to cover the fersiallitic brown soils developing at base of the moraine ridges, thus preserving parts of this horizon from further erosion. In the meanwhile, lithosols and rendzinas developed at the highest and steepest parts of the moraines. As fragments of Roman pottery and brick are sometimes found in these colluvial deposits, the erosional phase may be of anthropogenetic origin, related to Roman or Medieval phases of deforestation and cultivation.

1.2.3) The loess deposit of the Cordespino quarry. *(M. Cremaschi)*

Just below the crest of Mt. Cordespino, the marble quarries still active today, opened into the Rosso Ammonitico Veronese limestone, cut through a cover of Pleistocene deposits. The stratigraphic sequence described can be found at the North wall of the quarry. It is composed of the following units (fig. 5):

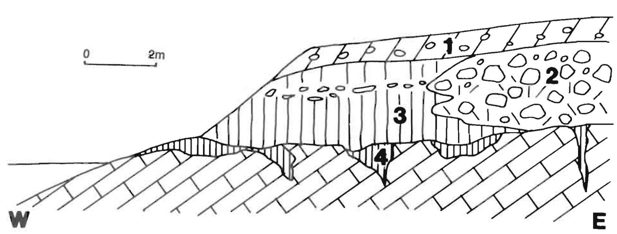

Fig. 5. The stratigraphic sequence of the Cordespino quarry; 1 - top soil; 2 - diamict; 3 - loess; 4 - Terra Rossa; 5 - limestone bed-rock.

Fig. 5. La successione stratigrafica della Cava Cordespino.

- Unit 1, A1 horizon, strong brown (10YR 4/4) sandy loam, including common limestone subangular fragments; it can be interpreted as a rendzina type soil, developed in the postglacial slope deposits and strongly affected by reworking due to the quarry activity.
- Unit 2, matrix supported diamict composed of angular and subangular large gravels (40% dolomite; 30% Oolitic limestone; 20% metamorphic rocks; 10% volcanic), abrupt lower boundary to unit 4; clear lateral and lower boundary to unit 3.
- Unit 3, loess: reddish brown (7.5YR 4/4) silty loam, fine angular blocky well developed, common thin voids, at the top it includes lenses of colluvial clasts; in the lower part it covers, with clear boundary to, unit 4, or it is included in dissolution cracks in the bed rock; few olive brown (2.5 Y 5/4) faint mottles and occasionally, small tongues. In the lower part of the loess cover some flint artifacts, possibly of Mousterian typology, have been collected; they do not show any evidence of postdepositional transport and therefore should be regarded as strictly in situ. The lower part of the unit seems to have been affected by ice lensings which originated a discontinuous laminar fabric in the deposit.
- Unit 4, Bt horizon of a relict paleosol of the Terra Rossa type; red (2.5YR 3/6) clay; common chert fragments, medium and coarse angular blocky well developed, common slikensides, few small voids; common Fe-Mn coatings; few clay cutans; sharp irregular boundary to the limestone. In thin section the horizon is constituted by clayey rubified plasma, with many stress cutans; lithorelicts are mainly composed of chert fragments; few fine sand sized quartz grains point to the existençe of eolian inputs in the Terra Rossa soil.

The Cordespino marble quarries cut through, at the top, moraine deposits that the Adige glacier seems to have put in place as a result of having overspilled the crest of Mt. Cordespino. These deposits cover a paleosurface upon which a Terra Rossa type soil developed, was deeply eroded, and later was covered by loess. The loess has been covered in part by the moraine flowing down from the Monte Cordespino; it has been affected by frost activity which led to the development of ice lensing and its upper part has been strongly colluviated. The presence of Mousterian implements within the eolian deposits indicates that they were deposited during the Upper Pleistocene, that they are more than 30,000 years old - and postpones the upper moraine to a more recent age. This presence recurs along the western margin of Mt. Cordespino all the way to Mt. Baldo.

1.2.4) The Gaium quarries. *(M. Cremaschi)*

These quarries, opened after the war between the 50s and the 60s, for the extraction of Oolitic limestone, have removed considerable stretches

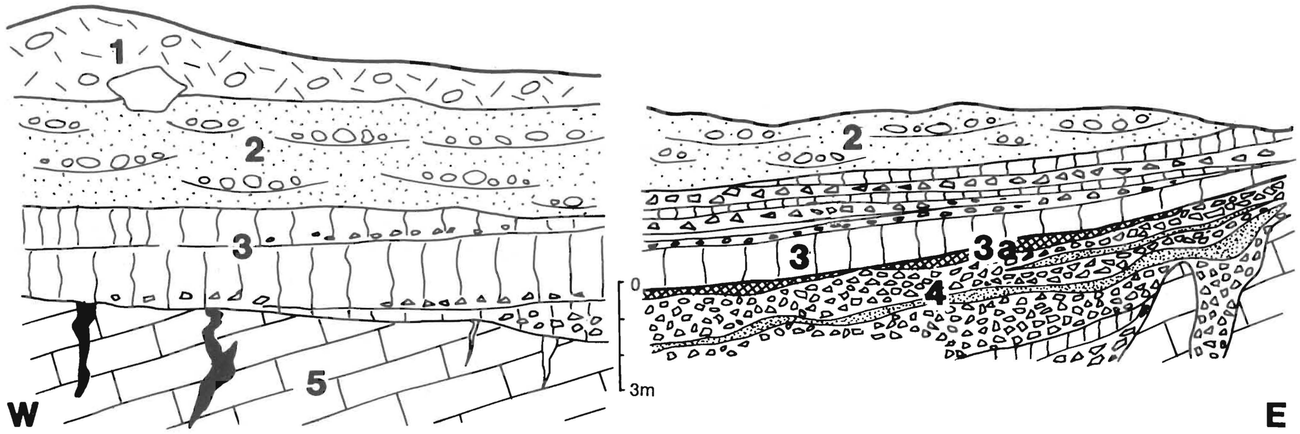

Fig. 6. The stratigraphic sequence of the Gaium quarries; 1 - moraine; 2 - fluvioglacial deposits; 3 - loess and colluvia; 3a - CaCO3 horizon; 4 - coarse and fine slope deposits; 5 - limestone bed-rock.

Fig. 6. La successione stratigrafica delle cave di Gaium; 1 - morena; 2 - depositi fluvioglaciali; 3 - loess e depositi colluviali; 3a - orizzonte calcico; 4 - depositi di versante, fini e grossolani; 5 - substrato calcareo.

of the outermost moraine ridge of the Rivoli system, exposing a complex stratigraphic sequence which includes fluvioglacial deposits, loess, slope deposits and the fill of a fossil karst which developed in the bedrock limestone (fig.6).

Starting from the top, the following units have been observed:

- Unit 1; outer moraine of the Rivoli system (Mt. Police unit), considerably heterometric diamict, including blocks and small pebbles (made up, from the lithological point of view, of limestone, dolomite, metamorphic and porphyritic rocks). The lower limit of the unit is planar and linear, underlined by a crust of calcium carbonate a few centimeters thick. At the top, on the ridge of the moraine, there is a rendzina type soil, while in the eastern part of the slope, a one meter thick, slightly rubified alfisol is preserved.
- Unit 2; fluvioglacial deposits; rounded clast supported and matrix-supported gravel distributed in lenticular bodies, which can be interpreted as channel fill. Towards the top the clasts become notably coarser. Erosive undulate sharp boundary to:
- Unit 3; chernozem in eolian and colluviated loess lying on fluviatile loamy clay: A1, dark brown (10YR 3/3) silt loam, coarse prismatic well developed, few faint mottles, mainly in the upper part of the unit, common thin tubular voids, common CaCO3 cutans on peds and into pores. It includes, in the western quarry (fig. 6) two levels of subangular limestone clasts. Clear boundary to:
- Unit 4; clast supported slope deposits:thick levels of subangular small angular gravels composed of Maiolica limestone (51%), Rosso Ammonitico marly limestone (25%), chert (11%), Oolitic limestone (5%) and Eocene volcanites (8%), occasionally imbricated towards S-W, intercalated by thin levels of brown massive loam. At the top of the unit is a cemented horizon decimeters thick, which constitutes the C Ca horizon of the overlying A1. Sharp boundary to:
- stratified Dogger limestone, dipping slightly S-SW, with karst pit and dolinas, the fill of which is composed by strongly weathered gravels in Terra Rossa - type soils and include mammal microfauna dating back to the Late Villafranchian (B. SALA, unpublished).

Micromorpholocical observations

(B. Van Vliet Lanoe, M. Cremaschi).

- Unit 4, the fine textured levels have to be interpreted as a alluvial levels. It is a sandy clay loam very rich in mica grains and in fragments of devetrified volcanic glass coming from the Eocene volcanites. A mull has been developed in drained conditions as lombric bioturbations form more loamy patches: no traces of hydromorphy are still visible. This loam is covered by a calcareous head, settled as a mud flow without preferential orientation. It reworks rounded fragments of limestone with some loam with volcanic glass and flint. Thin silty cap exists on the fragments associated with a weak frostshattering before being cemented first by pellets of micrite (bacterial calcite precipitation) and after by vadose calcite. These observations suggest the reworking of alluvial *grézès* by slumping under alpine conditions, followed by a rising of the watertable (vadose calcite).
- Unit 3, it can be divided in 3 subunits.

The lower part is constituted by a dark humic loamy clay, from colluvial origin, moderately rich in mica flakes, in rounded quartz grains and angular chert. Traces of an old granular microfabric resulting of lombric activity are visible in thin section though the present compactness of the sample, resulting of vertic activity (oblique stress cutans) which causes a porphyric (vomaskelsepic) microfabric. Nevertheless few vertical smooth fissures could be inherited from frost activity. Rare fragments of calcite or limestone subsist embedded in residual clay. A late biogenic calcite precipitation exist in the few remaining pores.

The medium horizon of the unit shows macroscopically a well developed prismatic structure. It is a clay loam much less humic than the lower horizon. It shows clearly the traces of a former granular microfabric fossilized into porphyric by intense prismation (mavoskelsepic). The loam fraction is much better sorted than in the former subunit but still reworking volcanic glass ; micas are abundant and the quartz grains are extremely rough. Some ferro-manganesian nodules look inherited. The only evident pedogenetic traces are constituted by a very weak clay illuviation, difficult to be distinguished from the vosepic fabric and diffuses organo-ferric precipitations.

The upper subunit, macroscopically characterized by a medium to coarse platy structure, is much more loamy an lighter in colour. Intense calcite precipitation cover the ped surfaces. It reworks some calcitic or limestone grains of loamy size, mixed with abundant rough quartz grains and mica flakes. Some dark organic fragments suggest the presence of ashes. The matrix is also porphyric but shows under microscope a microgranular biogenic fabric.

All those observations suggest the installation of an ishoumic soil, imperfectely leached in calcium carbonate (calcic mull) developed on a colluvial facies of grey wooded soils, probably responsible for the biogenic calcite precipitation in the lower head. This soil is buried by colluvial loess (large amount of mica and rough quartz grain) on which a new mull developed, The vadose calcite cementing the lower head is probably correlated with this event associated with a rising of the watertable. The sequence ends with a new burial below much less humic material, richer in loess and reworking some ashes. A deep frezing (platy structuration on about one metre deep) and new mud flow covers this subunit.

Radiocarbon datings

Two samples of humic acids have been extracted, from unit 3, by means of standard methods (ALESSIO et al., 1970) and the C14 age determined (Krueger Enterprises, INC, Geochron Laboratories Division).

The first sample collected just below the contact with the fluvioglacial deposits provided the date:

40 830 + 7 820 - 3 890 years B.P. (GX - 14028)

The second one, collected m 1.5 deeper, provided the date:

more than 42 000 years B.P. (GX - 13038)

1.2.5) The loess deposits of Le Basse.
(M. Ferraris)

Thick loess deposits have come to light along the western escarpment of the Adige paleo-river-bed, as a result of artificial excavation, North West of the Casina Le Basse, just beyond the Brennero motorway.

The top of the sequence consists of discontinuous planar-bedded gravelly fluvioglacial deposits made up of lenses with concave erosive bases. Outcropping below are five metres of loess, brown to olive brown (10YR 5/4, 2.5Y 5/4) silt loam, few voids, massive, $CaCO_3$ coatings into pores. The loess layer includes a buried A1 horizon, dark brown (10YR 4/4) silt loam, angular blocky poorly developed; few voids filled by $CaCO_3$ coatings. The sequence should be correlated to the one at Gaium, as the fluvioglacial deposits correspond to units 1 and 2 and the loess to the unit 3.

1.2.6) Discussion on the loess of Gaium and surroundings.
(M. Cremaschi, B. Van Vliet Lanoe)

The base of the Gaium stratigraphic sequence contains evidence of fluvial deposits and karst phenomena dating back to the late Early Pleistocene and to the Middle Pleistocene, which will not be discussed further. Unit 4 is made up of slope deposits composed of thermoclastic fragments, slightly reworked by transport.

It must thus be interpreted as the distal part of a talus detritus lodged into a depression of the bedrock. Its lithological composition and its dip point to the fact that it came from the East, from the limestone formations which today outcrop East of the Adige canyon (Chiuse d'Adige). Unit 3 is composed at its base by colluvial deposits which grade upward to eolian

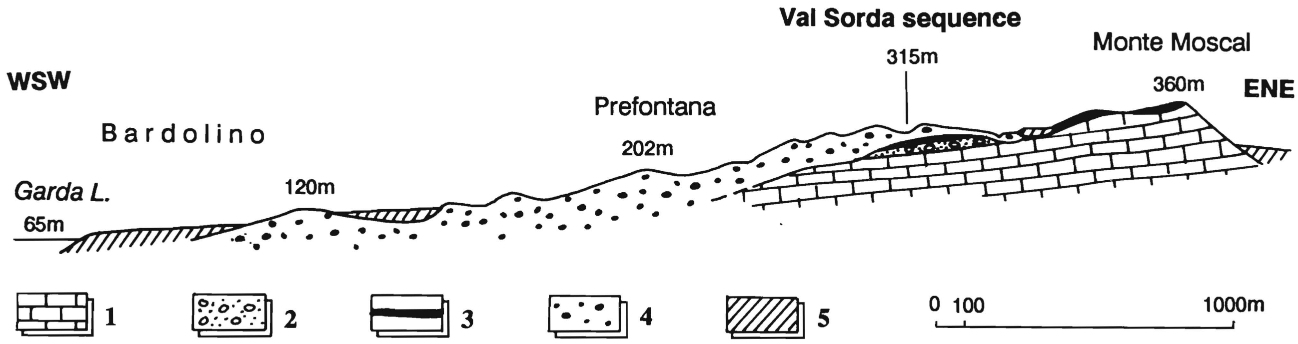

Fig. 7. Geologic section across the Garda moraines and the Monte Moscal; 1 - bedrock; 2 - till and fluvioglacial deposits (late Middle Pleistocene); 3 - loess (Upper Pleistocene); 4 - moraine ridges (Upper Pleistocene); 5 - fluviatile deposits (Holocene).

Fig. 7. Sezione geologica attraverso le morene del Garda e Monte Moscal; 1 - substrato; 2 - depositi morenici e fluvioglaciali (tardo Pleistocene medio); 3 - loess (Pleistocene superiore); 4 - cordoni morenici (Pleistocene superiore); 5 - depositi fluviali (Olocene).

sediments. The unit has been affected by soil forming processes, which led to the development of an isohumique soil of the mull calcique type: decalcification and accumulation of the CaC03 at the top of the underlying unit to the accumulation of humified organic matter and slight clay illuviation. Toward the East the unit is interstratified within the unit 4, and its thickness is gradually reduced. An ondulated erosional boundary marks the contact of unit 3 with the fluvioglacial deposits (unit 2); the passage to the overlying moraine (unit 1) seems to be in continuity of sedimentation and could be explained by a progressive approach of the glacier.

On the basis of the radiocarbon datings and of the correlations to the Val Sorda area sequences (see next chapter), units 1 and 2 can be attributed to the last glacial phase of the Upper Pleistocene, and the loess deposits (unit 3) and slope deposits (unit 4) are to be attributed, as the loess of Lubiara, to the early Upper Pleistocene. Furthermore the unit 3 of the Gaium sequence suggests a rather long but instable interstadial. Two stratigraphical positions can be proposed;

- it represents the lower Pleniglacial, with the two stabilisation phases which are characterized, North of the Alps by artic meadow soils (VAN VLIET LANOE, 1985) and attributed to the Glinde and Oerel intertadials (BEHERE & LADE, 1986)/Ognon II e III of La Grande Pile (WOILLARD & MOOK, 1982)
- it represents the lower part of the middle Pleniglacial, probably the Moershoofd or Moershoofd/Denekamp soil complex. In both phases, abrupt cooling exists just after.

Nevertheless, the progressive apparition of the loess fraction and radiocarbon dating suggests conditions closer to what we know from the second hypothesis on a regional scale.

The loess of Le Basse and those of Gaium are to be considered of the same age. Nevertheless, the former turns out to be thicker and the accumulation of organic matter seems less relevant as only one weakly developed soil intercalates with them.

1.2.7) The loess of Mt. Moscal and the stratigraphic sequence of the Valsorda.
(M. Cremaschi)

Monte Moscal is a sharp relief consisting of Miocene calcarenite and Oligocene limestone gently dipping S-W, which, during the Pleistocene, was reached several times, but never completely covered, by the Garda glacier. On the contrary, it acted as an obstacle, affecting the distribution of the glacial deposits. Within the moraines that surround Mt. Moscal, in correspondance with those of the Rivoli system, several order can be distinguished (fig. 2):

- The moraine ridge deposited by the greatest expansion (M.te Police unit) is the highest one and, in correspondence to Mt. Moscal, shows double-lobing. It is furrowed by wide eskers from which the fluvioglacial plain originated. Within the main moraine, several ridges decreasing in height towards the lake can be distinguished, and are to be correlated to the internal moraines of the Rivoli system.
- Outside the main ridge are the remains of an older, severely eroded moraine arc, to be correlated to the Mt. Crivellino unit and, as this unit, dated to the late Middle Pleistocene. Furthermore at Villa Albare (Albare unit) exists the fragment of a moraine ridge which has been considerably weathered by an ancient rubified and clayey soil, and is covered with loess containing

Mousterian artifacts. This latter ridge is to be dated Middle Pleistocene (MANCINI, 1960; FRAENZLE, 1965; VENZO, 1961).

The SW slope of Mt. Moscal is gently inclined (fig. 7). Leaning up against a moraine ridge that delimits its lower part there are fluvioglacial deposits which today are severely cut into by the Val Sorda river. Its upper part is covered with thick layers of loess and limited limbs of till deposits which are not linked to any recognizable glacial form. The Northern slope, facing the fluvioglacial plain, drops off over a cliff at the base of which we find talus determined by the periglacial degradation of the cliff itself.

On the left side of the deep canyon cut open by the Val Sorda river the following stratigraphic sequence can be observed. From the top (fig. 8):

- Unit 1: moraine: till deposits, gravels and cobbles (limestone, Dolomia, metamorphic, intrusive and volcanic rocks), matrix supported, massive, abrupt, undulated erosional boundary to:
- Unit 2: loess: in it the following pedogenetic horizons can be distinguished:

A11 cm 0-95: dark grey (10 YR 3/2) silt loam, with faint mottles, massive at the top; irregularly blocky at the bottom; very firm; scarse thin voids; in the lower part planar, non parallel lamination; linear clear boundary to:

A12 cm 95-340: dark brown (10 YR 3/3, 10 YR 4/2) silt loam, well developed very coarse prismatic superstructure, massive, very few pores, calcitans in pores; gradual boundary to:

C cm 340-410: greysh brown (10 YR 5/2) silt loam, few mottles; massive; few thin pores; linear clear boundary to:

II A1 cm 410-445: dark brown (7.5 YR 4/2) silt loam; massive;few small pores; rare few chert fragments; calcitans in pores; clear linear boundary to:

- Unit 3: buried paleosol in fluvioglacial gravel, composed, from the top, by the following horizons:

III B21 cm 445-480: brown (7.5 YR 4/4) sandy silt loam, common chert angular fragments; fine blocky poorly developed; few fine pores; $CaCO_3$ coatings in voids; linear clear boundary to:

IV B31t cm 480-565: dark reddish brown (5 YR 3/3) clay, common stones (slightly weathered metamorphic and volcanic rocks and chert), well developed medium blocky, few voids, common ferrimangans in the upper part; common slikensides in the lower part; common to many clay cutans; slightly calcareous at the top; clear wavy boundary to:

IV Cca cm 565-585: fresh stones (limestone, cherty limestone, metamorphic and volcanic rocks) and strong brown (7.5 YR 5/6) loamy sand; massive; many voids; widespread frequent $CaCO_3$ concretions; gradual boundary to loose gravel.

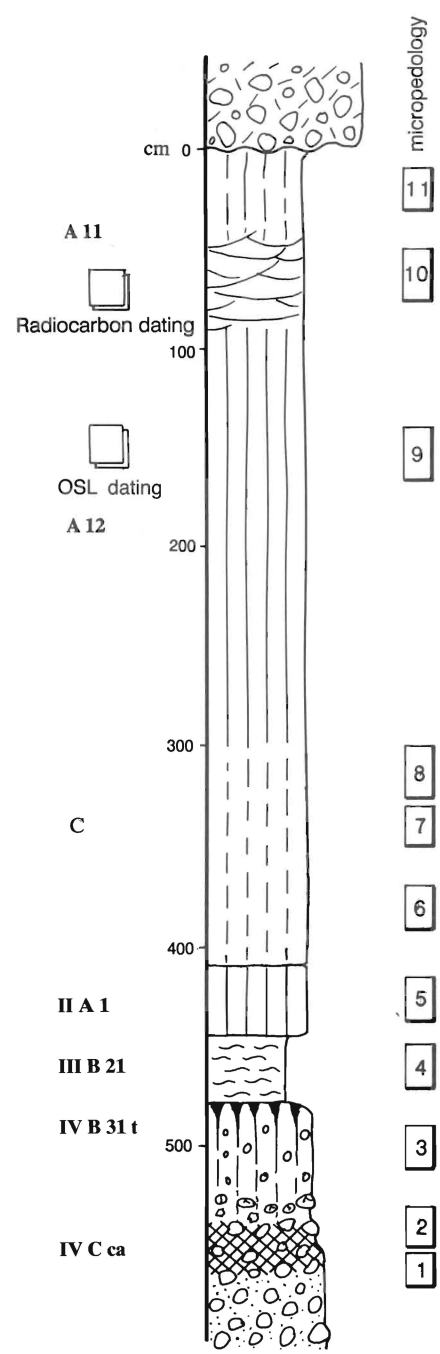

Fig. 8. The stratigraphic sequence of the Val Sorda.
Fig. 8. La successione stratigrafica della Val Sorda.

In the lower part of the Unit 3 the fluvioglacial deposits grade into till, which generally cover the bedrock, but occasionally, at its base, discontinuous lenses of weathered loess occur. The top of the bedrock is weathered in a clayey reddish brown (7.5 YR 4/4), 50 cm thick, B horizon, which probably corresponds to the "Ferretto inferiore" mentioned by NICOLIS (1889).

Routine textural and chemical analyses are exposed in tab. 1, cumulative curves in fig. 9.

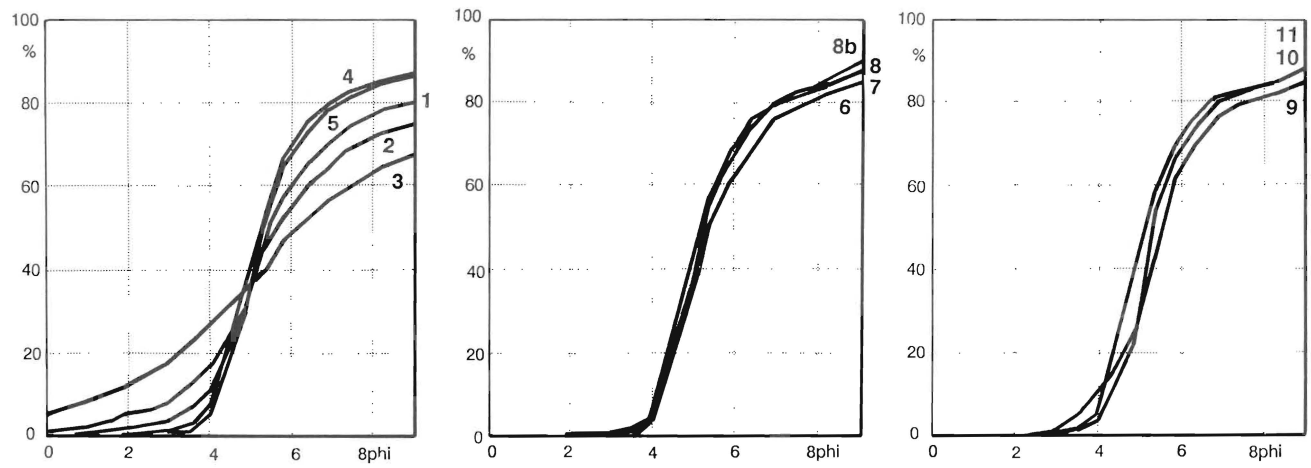

Fig. 9. Grain size curves of the Val Sorda sequence.

Fig. 9. Curve granulometriche della successione della Val Sorda.

Samples	Sand%	Silt%	Clay%	CaCO3%	C org.
14	10.6	74.5	14.9	2.0	1.62
13	5.6	82.7	11.7	2.0	1.36
10	4.4	83.1	12.5	0.7	1.08
9	4.0	83.6	12.4	0.9	0.95
8	6.6	80.5	12.9	2.9	0.67
7	4.5	85.1	10.4	6.8	0.86
6	7.3	77.2	15.5	3.0	0.75
5	7.5	79.4	13.1	0.7	0.38
4	4.7	82.3	13.0	0.7	0.58
3	11.1	88.9	19.8	0.3	0.50
2	16.2	58.5	25.3	0.3	0.42
1	26.8	40.9	32.3	0.9	0.24
paleo B31t	25.5	31.0	45.5	n.d.	n.d.

Tab. 1 - The Val Sorda Profile: textural and routine analyses.

Tab. 1 - Il profilo della Val Sorda: analisi granulometriche e di routine.

Radiocarbon dating

Humic acids have been extracted from a sample collected 50 cm below the contact between the chernozem in loess (unit 2) and the overlying moraine (unit 1) and dated by radiocarbon method at to:
27 880 ± 600 yr B.P. (R. 1854) (CREMASCHI et al., 1987).

Micromorphological characteristics
(M. Cremaschi)

The results of the micromorphological analysis (tab. 2) are in agreement with the field observation: we can distinguish, in the profile, a rubified paleosol (unit 3) which developed in gravel, covered by loess (unit 2) which includes two superposed isohumic paleosols.

- Loess: the micromorphological features common to the whole loess deposit are: a generally well-sorted ground mass made up of subangular quartz fragments and a large ammount of muscovite flakes, and of sometimes granular humified organic matter; the scarse presence of voids; a compact structure; the presence of shear planes; the considerable prevalence of the sandy and silty fraction over the clayey fraction. The related distribution falls between closed porphyric and gefuric. Compression due to the glacier which covered the loess deposit and placed the moraine on top of the sequence determined the scarsity of voids, the shear planes and the high bulk density (1.639 g/cm3).

The greatest differences between the different horizons consist of the distribution of coarse fragments (lithorelicts) and of pedofeatures.

The upper sequum includes the A11 and A12, C1 and C2 horizons, the sediment of which is composed of well-sorted silt and fine sand made up mainly of muscovite and quartz. It completely lacks lithorelicts and can thus be seen as an eolian loess. Voids are altogether missing from the A11 horizon, while the shear planes are very well manifest. Organic matter is abundant. CaCO3 infillings fill preexisting voids. In the A12 horizon voids are fairly common. These result from biological activity, are coated with calcium carbonate, have sometimes collapsed, and may be filled by sand grains. There are many bow-like distribution patterns in this horizon, marked by birefringent muscovite flakes. These patterns are considerably elongated and may be seen as striotubules (BREWER, 1976), or at least as features caused by the passage of earthworms (FITZPATRICK, 1985; BULLOCK et al. 1985). In the C1 and C2 horizons, the number of pedofeatures described diminishes considerably, whereas laminated clay and fine silt coatings appear. Biogenetic voids, on the contrary, are well preserved in the underlying A12 horizon. Inside these voids there are CaCO3 coatings associated with organic matter, suggesting that the process of mobilization of the CaCO3 was in-

HORIZON	MICROSTUCTURE, VOIDS	BASIC MINERAL COMPONENTS	BASIC ORGANIC COMPONENTS	GROUNDMASS	PEDOFEATURES
A11 (VS 10-VS 11)	Apedal vughs (FF)	As below	Common brown red and black fine organic particles	Very closed porphyric undifferentiated laminar distribution due to stress	CaCO3 nodules(infillings)
A12 (VS 8)	Apedal round and elongated vughs (FF)	As below,no coarse particles dark brown fine fraction	—	As before but dark brown	Common complex CaCO3 coatings and hypocoatings associated with O.M.
C1 (VS 7)	Apedal vughs (FF)	As below,no coarse particles organic matter in fine fraction	—	Very closed porphyric undifferentiated bow-like distribution (CC) laminar distribution due to stress	Complex CaCO3 and ferruginous coatings and hypocoatings (CC), impregnative
C2 (VS 6)	Apedal vughs (FF)	Coarse: 1-0.5 mm .5% quartz sandy: angular quartz + mica fine: silt and weackly bir. clay brown	—	Closed porphyric undifferentiated bow-like distribution patterns (C)	Impure clay coatings (F)
A1 (VS 5)	Coarse prismatic shear planes (F)	Coarse: 1-0.5 mm 1%, angular quartz + chert sandy: quartz + mica fine: silt and brown weackly bir. clay and O.M.	Charcoal (FC)	Closed porphyric undifferentiated bow-like distribution patterns (FF)	Impure clay coatings (FF), acicular CaCO3 coatings (F)
B21 (VS 4)	Coarse prismatic planes (F) vughs (FF 3%)	Coarse: 2-1 mm 10%,angular quartz,chert,volc. sandy: angular quartz + mica fine: mica,weackly bir. clay	Very fine charcoals(F)	Closed porphyric stippled spleckled	Fe-Mn hypo-quasi coatings in planes (F), CaCO3 coatings and hypocoatings (C)
B31 (VS 3)	Prismatic planar voids (CC) thin channels and vughs (FF)	Coarse: 5-2 mm 40%,subangular to angular flint + quartz + volc. sandy: angular quartz and scarse mica fine: weackly bir. clay and silt reddish brown	—	Porphyric,single spaced spleckled mosaic b-fabric (granostriated)	Bir. clay coatings into coarse fragments, impure clay coatings laminated and weackley birefringent (FF), fragmented clay coatings (C), impregnative Fe-Mn pedofeatures (CC)
B31 (VS 2)	Crack to prismatic planes (C) thin channels	Coarse: 5-2 mm 20% flint + quartz + volc. sandy: angular quartz fine: reddish clay and silt	—	Porphyric granostriated and reticulate striated b-fabric	Very disturbed clay coatings (CC), clayey micropan (F), compound impregnative amorphous pedofeatures (CC)
B32ca (VS 1)	Incomplete pedal large planes (F) thin channels (F) vughs (FF)	Coarse: 15-10 mm 40-50% polilith. sandy: angular quartz fine: reddish clay and micrite	Woods fragments impregnated by Fe/Mn	Close porphyric banded distribution of gravel spleckled b-fabric crystallitic b-fabric	Birifringent laminated clay coatings (C); fragmented clay coatings (CC), hypocoatings and coatings CaCO3, impregnative banded Fe-Mn pedofeatures, continuous CaCO3 crust at the top of the horizon

Tab. 2 - Brief micromorphological description: the Val Sorda profile.

Tab. 2 - Descrizione micromorfologica sintetica: il profilo della Val Sorda.

deed active during the development of the soil. Furthermore, small clay coatings, made of clay and silt and rich in organic matter and formed by eluvial processes which affected the overlying horizons, can be found in the C1 horizon.

The considerable thickness over which the organic matter is distributed, its progressive diminishment towards the lower part of the sequence and the poor occurence of the pedofeatures can be explained if the Val Sorda loess sequence is seen as a cumulative profile in which the pedogenetic processes have been opposed by a continuous but progressively diminishing (towards the top) deposition of dust. On the whole the profile can be considered a chernozem type soil, linked therefore to a dry steppe environment with, however, brief wet periods attested to by the occurence of silty clay coatings. In the II A1 and C1 horizons, quartz lithorelicts, which are numerous at the base, decrease rapidly in number towards the top of the sequence. The pedogenetic processes are attested to by impure clay coatings and a marked amount of humified organic matter in the micromass. Wood fragments and charcoals indicate the proximity of an exposed topographical surface to the IIA1 horizon. We can thus conclude that the lower loess deposits were condiserably reworked by colluvial processes. Slight pedogenetic processes, consisting mainly of the accumulation of organic matter and of the translocation of clay, led to the formation of weakly developed chernozem soil (Pl. 11,12).

- Paleosol in gravel: the IIIB21 horizon contains many decalcified lithorelicts and wood fragments impregnated with iron hydroxides. The micromass has a large amount of clay. The textural pedofeatures are represented by fragments of clay coatings dispersed in the ground-mass and by few impure clay and silt coatings connected to the voids. The horizon is thus seen as result of rearrangement by colluviation of a preexisting argillic horizon. Clay and silt coatings indicate processes of illuviation in a wet environment.

The IVB31t horizon is characterized by rubified, clayey micromass. The coarse part of the mineral components is made up of chêrt and quartz fragments coming from the dissolution and weathering of the parent material. Only towards the base of the horizon has there been observed a limestone fragment with corroded edges,in the process of dissolution. The strongly sepic b-fabric and the occurence of planes (slikensides) indicate a very dynamic horizon. Indeed, the abundant and thick clay coatings are very much disturbed and are being absorbed by the ground mass. The horizon is marked off at the base by a millimeter - thick Ca CO3 crust which marks the beginning of the calcic horizon. At the top of it, laminar patterns appear on clay coatings which are impregnated by manganese dendroid concretions.

The underlying IV C ca horizon consists of unweathered gravel and sand which still display their original stratification. The original packing voids of this horizon are filled with two different types of micromass, placed there one after the other. The first is composed of rubified and microlaminated clay coatings which are often fragmented and included in micritic calcite. This calcite impregnates the clay coatings and fills the original voids they left. It furthermore assumes the form of coatings and hypo-coatings into the tubular voids produced by ancient roots.

The processes which gave rise to the IVB31t horizon – decalcification, ferri-argilluviation and shrink-and-swell determined by the clay content – are of fersiallitic nature, attesting to a climate of well marked seasons, not very different from the present (CREMASCHI & SEVINK 1987; CREMASCHI, 1987a). The superimposition of crystallitic pedofeatures on the clay coatings indicates, in the last phase of this soil's development, the rising of belt of the CaCO3 precipitation. These features may have been the product of an increase in evapotranspiration caused, for example, by the decline of the arboreal cover resulting from the drying of the climate. We could otherwise advance the alternative hypothesis that this is due to difficult drainage at the interface between the B and C ca horizon resulting from the filling of voids by CaCO3, and/or from the increase of precipitation, and from the rising of the water table. Hence, the precipitation belt of CaCO3 rises in the soil's profile, leading to the incrustation of previously deposited clay coatings.

Pollen content
(C.A. Accorsi)

Ten samples from the Val Sorda sequence have been submitted to pollen analysis, and the results are exposed in the pollen diagram (fig. 10); pollen grains occur in different amount in the loess and in the underlying colluvium, while they are lacking in the sample collected in the rubified paleosol at the base of the sequence.

Absolute pollen frequencies

The number of pollen grains in one gram of sediment clearly decreases from the top of the sequence downwards, ranging from 11,500 grains per gram, at the top of the loess, to 100 grains in the colluvial deposit at the base. The reduction of the pollen content along the sequence, while progressive, is not regular: three rises appear in the curve in fig. 10 in correspondence of the top of the loess, in its middle part, and in the base of it. These levels, besides a higher pollen content, are richer in fungal remains, and correspond to picks of arboreal pollens and probably they indicate periods in which, locally, the vegetation and the soil forming processes were better developed and pollen grains were added by percolation to those still existing as particles of the loess deposit (URBAN, 1984)

The pollen diagram

Several observations can be inferred from the pollen diagram in fig. 10:

- The spectra refer to a local vegetation which does not change very much all along the sequence, and are indicative of an open landscape widely extended around the site. In the lower part of the sequence, the sum of the arboreal plants does not exceed 5%; while at the top it reaches the maximum value (20%), which is still too low to be representative of a woody landscape.
- The vegetation in situ is to be related to steppe environment; the *Graminae* and the *Cichoriaceae* are dominant and are represented by different species as suggested by the large variability in which the pollen grains of these families occur. Among *Graminae*, *Stipa* is represented, a genus in which xerophilous plants, which are characteristic of the Euroasiatic steppe, are also included. Furthermore *Asteraceae* (*Artemisia*, *Centaurea*), *Caryophyllaceae*, *Ranunculaceae* are represented together with *Umbelliferae*, *Leguminosae*, *Labiatae*, *Liliaceae*, *Galium*, *Helianthemum*, *Armeria*, *Dipsacaeae*, *Plantago*, *Chenopodiaceae* etc. The aspect of the local plant associations does not show important differences all along the diagram and mainly in its lower part. However, there are

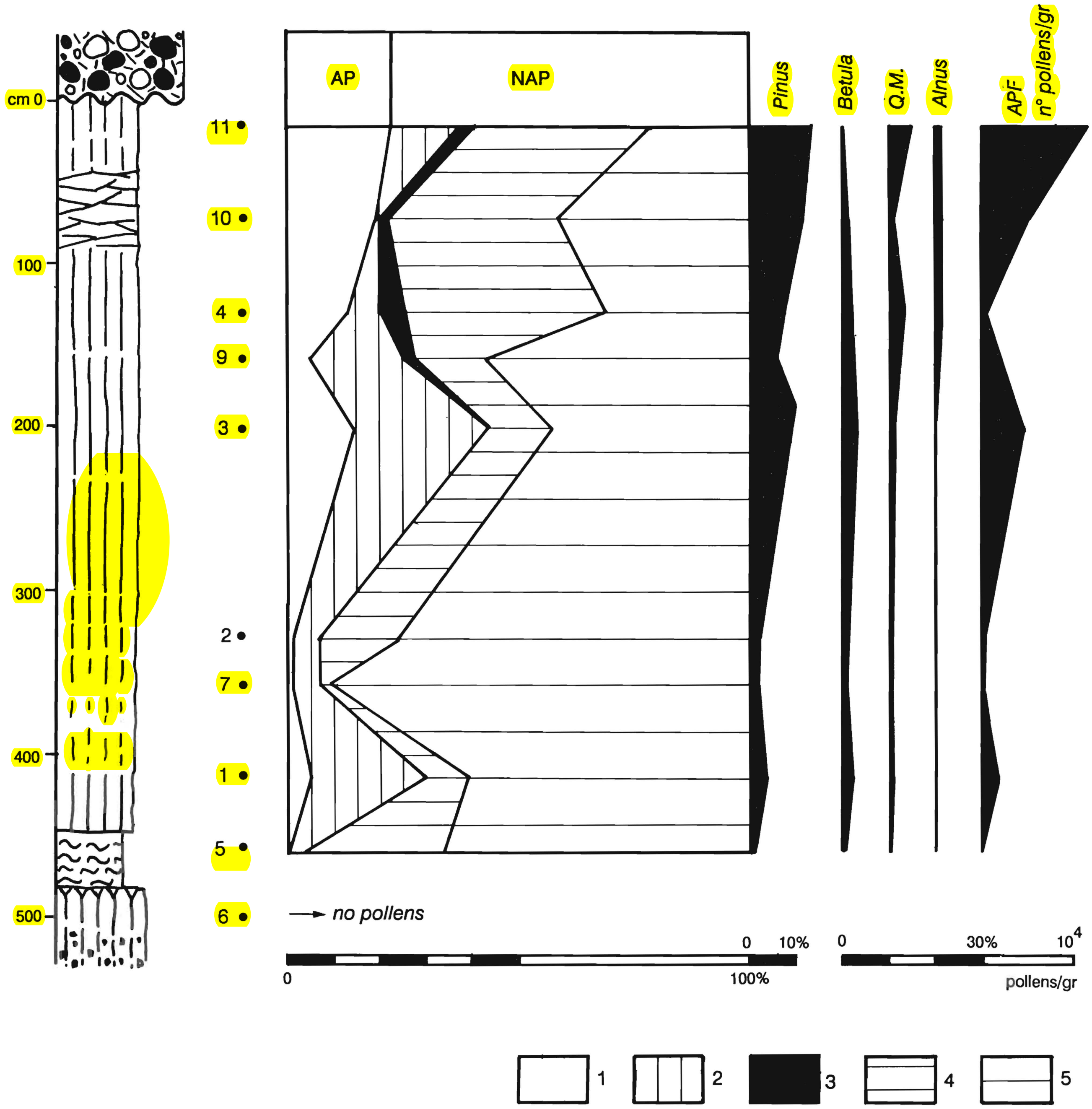

Fig. 10. The pollen diagram of the Val Sorda sequence: 1- A.P. arborial pollen; 2 - others N.A.P.; 3 - *Cyperaceae*; 4 - *Cichoriaceae*; 5 - *Graminae*.

Fig. 10. Il diagramma pollinico della successione stratigrafica della Val Sorda; 1 - A.P. pollini arborei; 2 - altri N.A.P.; 3 - *Cyperaceae*; 4 - *Cichoriaceae*; 5 - *Graminae*.

levels in which *Artemisia* and *Chenopodiaceae* occur in higher amount that could be related to a dryer environment; on the contrary, in the upper part of the diagram, hygrophylous species (*Cyperaceae*) appear.

- The arboreal plants are generally represented by *Pinus* and *Betula*, while occasionally a slight amount of *Quercus* appears in the levels in which the pollen grain content becomes higher. At the top of the sequence, the forest assemblage and its species increase; *Picea*, *Alnus*, *Populus* and thermophilous broadleaf trees (in addition to *Quercus*, also *Ulmus*, *Carpinus*, *Corylus*, *Castanea*, *Juglans* occur) are represented, reaching 5% percent. In a context of poor arboreal cover, the occurence of these trees should be connected to input from areas far away from the site, in which, due to local conditions, arboreal species survived during the Würm glacial period.

Discussion

The vegetational changes, documented in the pollen diagram, both of the local and of the outer flora, put into evidence some climatic events and indicate a chronological attribution for them. The local vegetational assemblage is fully in agreement with the nature of the substratum: the steppe vegetation evolved in loess and originated a chernozem type soil. According to the environmental requirements of the loess sedimentation the vegetational association originated in a cold and dry climate; the same environment is indicated by the arboreal species occurring all along the diagram which includes *Pinus* and *Betula*. In this context, which is of glacial type, some climatic ameliorations are recorded. At the top of the sequence, there is evidence of an increase of temperature and humidity: pollen content indicates that the arboreal species, *Quercetum* and *Cyperaceae* are better represented, Picea and alder trees appear. Due to the radiocarbon dating on humic acids content of this level (27 880 ± 600 yr B.P.) the climatic amelioration could be correlated to the Denekamp interstadial period (Arcy-Kesselt in France and Krinides in Macedonia). Stratigraphic evidence of this period has also been found in pollen diagrams studied at Venice (BORTOLAMI et al., 1977) and in the Po plain, South-West from Verona (SORBINI et al., 1984), in which similar pollen assemblage occurs, but due to the local conditions, they are richer in arboreal species. In the stratigraphic sequence of the Val Sorda two older phases of slighter climatic amelioration occur, which are indicated by higher arboreal pollen and fungal remains content. They cannot be dated exactly and could represent short phases in which the rate of loess sedimentation diminished and the vegetational cover improved.

Optical dating from the Val Sorda sequence.

(M.J. Aitken, C. Mc Elroy, D. Questiaux)

Optical dating of unburnt sediment was first reported by HUNTLEY et al. (1985). It is a companion of TL but the dating signal is optically-stimulated luminescence (OSL) obtained by shining a beam of photons onto the sample; for TL the signal is stimulated by heating. For unburnt sediment the major advantage of OSL over TL is the much smaller zero-age signal - for TL this can be an appreciable part of the total signal from samples even for samples that are more than 10 000 years old.

As with TL the basic principle is that because windblown and waterborne sediment has had exposure to sunlight and daylight the previously - acquired dating signal is reduced to very near zero (in the case of OSL) at the time of deposition. When subsequent sediment cuts off the light the signal begins to built-up again because of the effect of nuclear radiation on the various mineral constituents. This radiation comes from radioactive impurities (mainly thorium , uranium and potassium - 40) in the sediment, together with a small contribution from cosmic rays. On excavation the sample must be rigorously shielded from light and processed in the laboratory in similar stringent conditions. The essential basis of dating can be expressed by the equation

$$\text{age} = \frac{\text{paleodose}}{\text{annual dose}} \qquad (1)$$

where *paleodose* refers to the evaluation (derived from the size of the OSL signal) of the total dosage of radiation that the sample has received since it was last exposed to light , and *annual dose* is determined from radioactivity measurements - the natural radioelements concerned have very long halflives and hence it is presumed to have been constant. The radioactivity measurements both within the laboratory and on site.

Here we report the first application of the new technique to European loess using 4-11 microns polymineral grains. Like HUNTLEY et al. (1985) we have used green light (514 nm) from an argon laser for stimulation, but in addition we have made parallel measurements with an array of infra-red diodes (following the demonstration by HUTT et al. (1988) that infra red stimulation could be used for dating). The results reported are based on preliminary measurements and should reguarded primarly as a demonstration that optical dating is applicable to loess, holding promise of a definitive chronology back to about 50 000 years at any rate. Outlines of TL and optical dating is referred to AITKEN (1989, 1990).

The sample

It was collected, following laboratory instructions regarding shileding from light; weight was 1-2 kg, two metres below the top of the loess deposit (fig. 8).

Preliminary result

Using the additive dose method the paleodose was determined to be 220 Gy and the a-value was 0.072. From laboratory measurements with a high resolution gamma spectrometer the annual dose, after allowance for as-found water content of (10 ± 5) %, was estimated as 6.1 Gy/ka. From equation (1) this yelds an age of 36 ka; the estimated error limits are 5 ka. The age obtained using the infrared diode array for stimulation was in agreement.

This result must be regarded as preliminary until on-site measurements have been made. Also there is the possibility that the OSL age understimates the true age by up to 20%. This is because a poorly understood form of anomalous fading which afflicts the TL and OSL signals from loess on some european (and chinese) sites. It is not yet known wheter this affliction is present in loess of the same origin as the Val Sorda sample.

Comment

The result is highly encouraging for future OSL work on loess of this region; samples from the Bagaggera section are currently being processed. The OSL age is stratigraphically consistent with radiocarbon dating mentioned above (see specific paragraph); also it is consistent for loess of the Gaium sequence which lies in the same stratigraphic position (see paragraph 1.2.4).

1.2.8) The loess of San Michele and Incaffi.
(M. Cremaschi, M. Ferraris)

Extensive loess deposits crop out on Mt. Moscal, outside the moraines related to Garda lake. These deposits can be correlated, for their lateral continuity and lithostratigraphic characteristics, to those which, in the Val Sorda series, at the "Le Basse" and at "Gaium", are covered with moraines and fluvioglacial deposits. Of these, two significant outcrops can be described as follows:

S. Michele cave: an artificial cave has been dug into thick loess cover. According to what can be observed at its walls, we have the following sequence of horizons (fig. 11):

- cm 0-280: loess; brown (10 YR 5/4); silt loam; massive; few tubular voids; covered by thin CaCO3 cutans; gradual boundary to:

- cm 280-320: A1 b; dark brown (10 YR 4/4); silt loam; fine

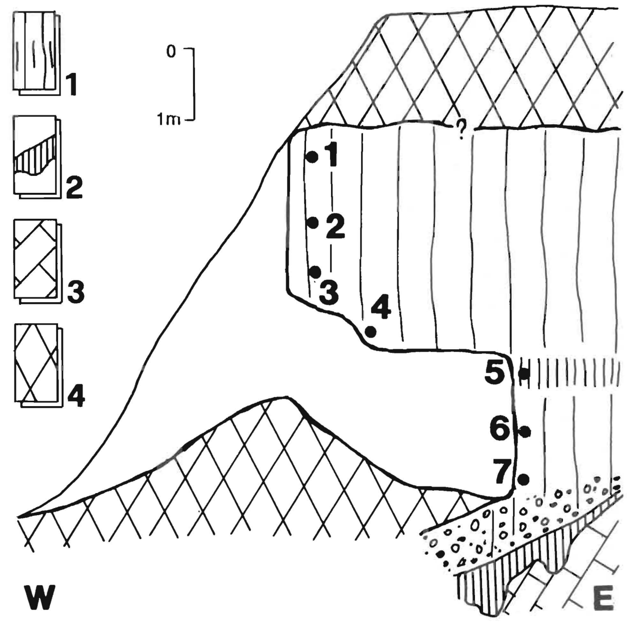

Fig. 11. The stratigraphic sequence of S. Michele; 1 - loess and interlayered soil; 2 - Terra Rossa soil; 3 - limestone bedrock; 4 - top soil and collapsed material; 1-7 - samples for grain size determinations (cfr. fig. 12)

Fig. 11. La successione stratigrafica di S. Michele; 1 - loess e suolo interstratificato; 2 - suolo tipo Terra Rossa; 3 - substrato calcareo; 4 - suolo sommitale e materiale franato; 1-7 - campioni sottoposti ad analisi granulometrica (cfr. fig. 12).

subangular blocky poorly developed; common tubular voids, covered by thin CaCO3 cutans; gradual boundary to:

- cm 320-460: loess; brown (10 YR 5/4) silt loam; massive; few tubular voids; few CaCO3 cutans; at the top the horizon includes few small pebbles; not exposed boundary to:

- paleosols developed in Miocene calcarenites: reddish brown (5 YR 5/6) clayey B horizon; fine-medium angular blocky. The horizon is preserved in dissolution pockets in the bedrock.

At the top of the buried chernozem (Alb), Venzo and Mancini (VENZO, 1961) found a Mousterian red-flint artifacts.

The top of the loess cover, which is not exposed in the San Michele profile, has been observed and described at the Incaffi profile, along a road-cut close to the western ridge of Mt. Moscal:

A1 0-15 cm: brown (7.5 YR 4/4) silt loam; fine granular well developed; many coarse voids; friable; gradual boundary to:

B1 15-70 cm: yellowish brown (10 YR 5/6) silt loam; fine subangular blocky poorly developed; common thin voids; few CaCO3 cutans; clear linear boundary to:

A11 70-130 cm: dark yellowish brown (10 YR 3/4) silt loam; fine to medium blocky poorly developed; common thin tubular voids; covered by many CaCO3 dusty cutans; gradual boundary to:

A12 ca 130-150 cm: dark brown (10 YR 3/3) silt loam; fine blocky poorly developed and massive; few pores; many CaCO3 tubular concretions; common weathered fragments of decalcified bed-rock (Miocene calcarenite); pale olive (5Y 6/3) and yellow brown (10 YR 5/4); gradual boundary to the unweathered bed-rock.

Textural characteristics are exposed by fig. 13, B1 and A11 samples are to be regarded as loess deposits, while A12 samples are enriched in clay and sand due to their colluvial origin, as also attested to by large fragments of the bedrock included in them.

From the micromorphological point of view, the following characteristics have been recognized:

- B1 - no lithorelicts, coarse fraction (125 - 63 microns) mainly composed of mica and quartz grains, ground mass of the intertexic type, low organic matter content, clear brown in colour; common void, with few CaCO3 coatings, partly dissolved, common voids (channels and interconnected chambers), fairly common red clay coatings, laminated.
- A11 - few lithorelicts of partly decalcified limestone, coarse fraction composed of mica and quartz grain, crumby pedality, poorly developed, ground mass dark brown in colour very rich in organic matter content, undulic; common impregnative CaCO3 features and infillings, few allocthonous Fe Mn nodules.
- A12 ca - common lithorelicts, coarse fraction composed of coarse sandy quartz and mica, ground mass more rich in clay and rich in organic matter content, insepic, common voids, many impregnative CaCO3 features.

The Incaffi profile represents a chernozem soil developed on colluvial material and loess, quite similar to that of the Val Sorda, but exposed to the Postglacial and present pedogenesis. The main processes which affected the profile are: - decalcification the B1 horizon and precipitation of CaCO3 in the A12 ca horizon, - removal of the organic matter and deposition of clay cutans in the B1 horizon. A high accumulation of humified organic material in the A11 and A2 horizons is to be related to Pleistocene weathering of the loess deposits, which acted here as it did in the unit 2 of the Val Sorda profile.

1.2.9) Discussion.
(M. Cremaschi)

The profiles here described provide detailed documentary evidence of the geologic and pedologic events which took place in the area during the entire Upper Pleistocene, particularly those linked to the deposition of the loess.

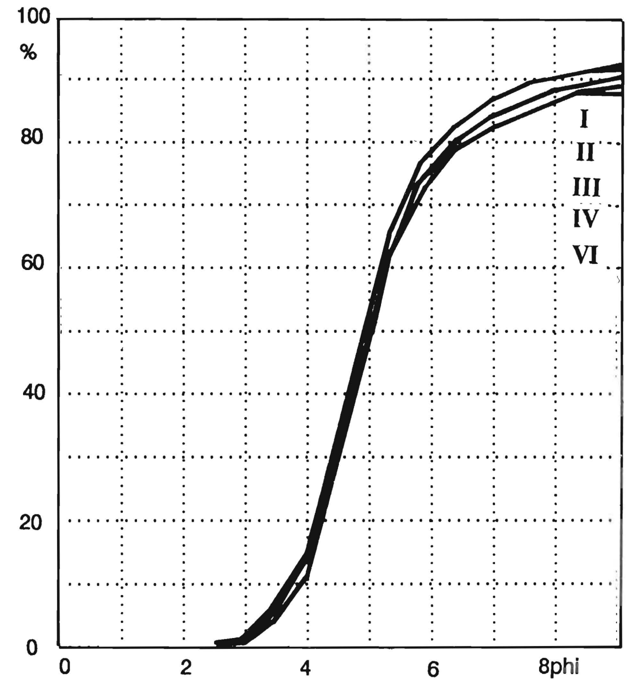

Fig. 12. Grain size curves of the S. Michele sequence.

Fig. 12. Curve granulometriche relative alla successione stratigrafica di S. Michele.

The rubified paleosol at the top of unit 3 of the Val Sorda sequence can be attributed to the Eemian interglacial period and displays characteristics much like those of the post-glacial soils described for the area of Rivoli. The processes which gave rise to this soil are decarbonatation, argilluviation and rubifaction, providing evidence of a climate subject to contrasting seasons, not unlike today's.

The overlying colluvial deposits testify to the degradation of the paleosols in a damper and colder environment. The deposition of loess began gradually, and since colluvial deposits are still present in the first horizon of loess, it seems to have been accompanied by wet phases. The pedogenetic characteristics of the II A1 horizon allow us to distinguish the presence of a buried chernozem at this level. The successive loess cover, lacking in organic matter and pollen content, seems to indicate severe dry and cold climate conditions. Towards the top of the sequence, the pedogenetic features are always more clearly manifest, accompanied by an increase in organic matter and pollen content, and by the occurence at the top of the sequence of thermophile plants. All these elements are evidence of a phase of temperate climate, which the radiocarbon dating of the Val Sorda sequence can be referred to, and which is to be identified with the Hengelo-Arcy interstadial period.

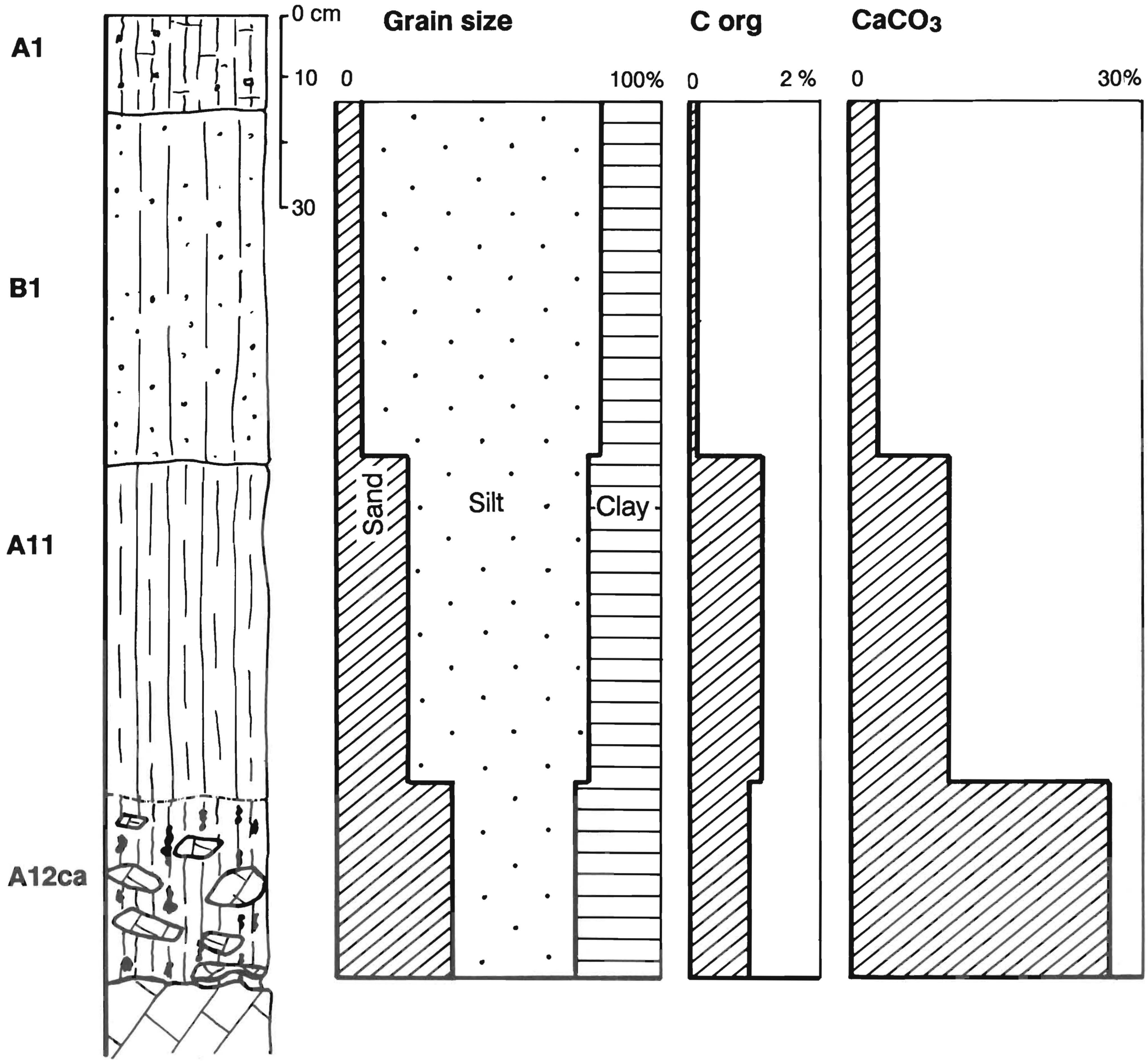

Fig. 13. The Incaffi profile.

Fig. 13. Il profilo di Incaffi.

The placement of the moraine indicates the resumption of glacial conditions in the latest Upper Pleistocene and a greater advance of the eastern margin of the Garda glacier with respect to the preceding glacial phases.

Buried A1 horizons occur less frequently at the San Michele profile, whereas the thickness of the loess lacking organic matter is notably greater. An higher rate of eolian sedimentation in this area, favored by stational factors, could explain this case. The Mousterian artifact, found by Venzo and Mancini, is of stratigraphical relevance in that it contributes, along with the dates obtained from the loesses of the Rivoli area and the radiocarbon dating of the Val Sorda, to placing the loess sedimentation mainly at the Upper Pleistocene preceding the Hengelo-Arcy interstadial period.

In the Val Sorda profile the original features of chernozem in loess have been preserved thanks to the fact that the uppermost moraine isolated them from present day pedogenetic processes.

From a lithostratigraphic point of view (fig. 12) the profiles of Incaffi and S.Michele are rather similar to that of the Val Sorda: colluvial material is present at the bottom, while pure loess occurs in the upper part.

The organic matter content of the San Michele sequence is weak and can be compared to that of Le Basse sequence.

The loess, all over the Moscal hill, is not protected by sedimentary cover and is subjected to present pedogenesis. This acts by means of "brunification" processes (DUCHAUFOUR, 1977) affecting the Pleistocene chernozem developed in it. The organic matter is oxidised and removed from the profile, the color of soil horizons turns from dark brown to brown, the $CaCO_3$ is leached on a thickness of about one metre, and clay translocation appears.

1.2.10) Conclusions on the loess of the Rivoli area. *(M. Cremaschi)*

The stratigraphic position of the loess deposits in the Val Sorda - Rivoli area is rather similar: loess sedimentation affected the area mainly during the first Pleniglacial period of the Upper Pleistocene, during which the outer margin of the glaciers stopped in a more internal position within the pre-Alpine margin. On the contrary, during the second Pleniglacial period the glaciers expanded further southwards and covered the previously deposited loess; no loess deposit of this period has been observed in the area.

Environmental conditions during the loess sedimentation are provided by paleopedological characteristics and pollen content. The base of the sequences (both in Val Sorda and in Gaium) is constituted by colluvial material in which the eolian silt is mixed with soil sediment or other fine colluvial materials; this fact indicates environmental conditions ranging from dry and cold to wet and cold climate. To this phase, another one follows in which climatic conditions were dry and cold : this is the phase in which sedimentation of loess with a slight ammount of organic matter occured and, as testified to by the Val Sorda sequence, the pollen association indicates very dry and cold steppe, in which arboreal plants and grasses of humid environment are very scarce. In the Val Sorda sequence, this phase is intercalated by a phase of weak isohumic soil formation which corresponds, probably, to the development of the buried soils detected in the S. Michele and Le Basse sites. At the top of the loess sequences, isohumic soil-forming processes interacted with the loess sedimentation; the lacking of well developed clay illuviation suggests that environmental conditions were still arid. The pollen record indicates a slight but progressive increase of arboreal plants in this phase, which, on the ground of the radiocarbon dating of the Val Sorda sequence, should be related to the Hengelo - Arcy interstadial period.